Effect of Width, Thickness, and Length on Static Bending of Red Meranti (*Shorea* sp.)

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Abstract. This study aim to determine the wood size effect of the width, thickness (depth), and length on the static bending strength of red meranti (*Shorea* sp.). The results of the study are expected to provide information and evaluation in the application of wood as the structural material. Specimen testing uses small specimens and defects free of the clear solid wood standards DIN 52182-77 for moisture content, DIN 52183-76 for wood density, and DIN 52186-78 for static bending strength (Modulus of Elasticity/MoE and Modulus of Rupture/MoR). Statistical analysis (ANOVA) and LSD (Least Significant Difference) test at 95% confidence level were used to analyze the significant effect and difference between treatments. The results showed a significant difference between treatments, where increasing in width will decrease the average value of static bending strength (MoE and MoR), and in contrary increasing in thickness (depth) and length will increasing the average value of of static bending strength (MoE and MoR).

INTRODUCTION

Wood as material has been known and used by humans for a long time, currently known many other materials such as concrete, metal, plastic, glass, brick, stone and others, but the need for wood continues to increase due to its unique nature, which tends to be small in size and weight but has high strength especially compared to metal and concrete.

Many theory and research on concrete and metal materials state that the size was affects to its strength, where the longer the dimensions of a material, the lower the strength, caused by the weakness in the connection of the material, known as link weakness theory that describing as the link in chain. Major developments of the theory were made by Weibull [1] who verified his results with tests on many different brittle materials, but apparently not timber. Wood is also formed from the link of various wood tissues, but the strength of wood is difficult to assess because wood is a non-homogeneous and anisotropic material (unlike other homogenous materials) due to the orientation of the fiber, and other properties such as moisture content, density, structure and texture of wood tissue, grain angle, chemicals content, annual/growth ring width, direction of loading, and the size of the wood varies affecting to its strength properties. Although the effect of homogeneous material size has been widely known, the effect of wood size as non-homogeneous material needs to be studied more because of its varied nature.

Size effect of bending strength for wood members was studied by several researchers [2-4]. However, studies on the effect of size in relation to the link weakness theory of hardwood joints or local timber have not been widely studied. This study aims to determine the wood size effect of the width, thickness (depth) and length to static bending strength properties of red meranti (*Shorea* sp.), so it can be considered and applied to the use of wood sizes as raw material for building structures.

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MATERIAL AND METHOD

Experimental Procedures

The physical and mechanical properties of red meranti were tested using the DIN standard, where normal moisture content (DIN 52183-77), normal density (DIN 52182-76), and static bending strength (DIN 52186-78) were tested.

The experimental data using laboratory test from the small specimens and defects free of the clear solid wood red meranti (*Shorea* sp.) The red meranti logs was cut with quarter sawn method to get the correct radial & tangential plane orientation. Specimens were air dried and stored in the constant room at temperature of 20±1°C, and relative humidity of 65±3% until the normal moisture content was reached (±12% as required of DIN 52183-77 Standard), so that the normal density and static bending strength of red meranti can be tested.

The treatments (variation specimens size) according to DIN Standard as shown in Table 1 for the static bending strength test, where the Modulus of Elasticity (MoE) and Modulus of Rupture (MoR) were determined that affected by the width, thickness (depth), and length. The width and thickness (depth) of specimen was changed, so the span length and total length of specimen was also changed according to DIN 52186-78 provision. Because of the variation in width and depth, the specimens was tested in flatwise (B and D) and edgewise orientation (C and E), while A as a control.

TABLE 1. Dimension of Red Meranti specimens for static bending strength test (din 52186-78 standard)

Treatments	Width (W) x Depth (D) (mm)	Span Length (15 x D) (mm)	Total Length (18 x D) (mm)
A	20 x 20	300	360
B	30 x 20	300	360
C	20 x 30	450	540
D	40 x 20	300	360
E	20 x 40	600	720

The static bending strength test was performed on Universal Testing Machine of manufacturer "Wolpert". The direction of the loading force on the static bending strength test was on the tangential direction (to the radial plane) according to the DIN 52186-78, where the loading given on one center point of specimen until the specimen destructed.

Modulus of Elasticity (MoE) shows the stifness or the ability to endure loads in the non-permanent elastic region, MoE does not indicate as the strength. The MoE of an object can be calculated by loading the stress applied to the object and the strain that occurs. To calculated Modulus of Elasticity (MoE) the equation as follow:

$$MoE = \frac{l^3 \times \Delta F}{4 \times a^3 x b \times \Delta f} \quad (1)$$

Where, l is span length (mm), ΔF is stress at proportional limit (elastic region) (N), a is the thickness (depth) of specimen (mm), b is the width of specimen (mm), and Δf is deflection or strain of specimen (mm).

Modulus of Rupture (MoR) indicated as strength which states the maximum ability to endure the load until it is permanent damaged. To calculated Modulus of Rupture (MoR) the equation as follow:

$$MoR = \frac{3 \times Fmax \times l}{2 \times a^2 \times b} \quad (2)$$

Where, Fmax is the maximum stress (N) until specimen destructed, l is span length (mm), a is the depth of specimen (mm), b is the width of specimen (mm).

Statistical Data Analysis

Analyzing data using statistics Analysis of Variance (ANOVA) in Completely Randomized Design (CRD), with the confidence level of 95%. The moisture content (MC) and wood density using 20 replication, and 10 replication for static bending test. If there was a significant effect of treatment on ANOVA, the test continued with the Least

Significant Difference Test (LSD test) to determine the differences average value of MoE and MoR between the treatments.

RESULT AND DISCUSSION

Table 2 shows the normal moisture content and normal wood density of Red Meranti (equilibrium in constant room). The normal moisture content was 12.41% and the coefficient of variation (CV) was 1.62%, which were uniform. The normal moisture content from specimens has met the requirements of the standard DIN 52182-77 (MC ±12%) for the static bending strength testing, while the normal density of Red Meranti was 0.61 g/cm^3 and coefficient of variation (CV) 1.32%. This means that Red Meranti was classified in the moderately heavy on density classified class, and is included to the Wood Strength Class II of the Indonesian Wood Density Classification [5].

TABLE 2. Moisture content and wood density of Red Meranti equilibrium in constant room

Moisture Content (MC) (%)		Wood Density (g/cm^3)	
Average	Coefficient of Variation	Average	Coefficient of Variation
12.41	1.62	0.61	1.32

Table 3 shows the static bending strength test (Modulus of Elasticity/MoE and Modulus of Rupture/MoR) of Red Meranti specimens, where the averages MoE and MoR varied in treatments based on difference in size of width, thickness (depth) and length of specimens.

TABLE 3. Static bending strength test of Red Meranti based on difference in width, depth, and length

Treatments	Modulus of Elasticity (MoE)		Modulus of Rupture (MoR)	
	Average (N/mm^2)	Coefficient of Variation (%)	Average (N/mm^2)	Coefficient of Variation (%)
A	9,801.36	12.86	76.24	7.55
B	4,122.86	11.11	49.39	10.66
C	17,975.94	14.98	92.39	4.68
D	2,011.51	12.24	34.25	8.88
E	36,598.63	7.03	132.96	5.76

The average values of the MoE test based on the difference in specimen size varies from 2,011 – 36,598.63 N/mm^2, while the average values of the MoR test varies from 34.25 – 132.96 N/mm^2. The lowest average value in MoE and MoR was treatment D, meanwhile the highest average value was treatment E.

The increasing in specimen size does not always lead to a decreasing in strength as in the Weibull's link weakness theory. In this study, the decrease in strength only occurred with the increasing of the width of the Red Meranti specimen, while the increasing in thickness and length of the Red Meranti specimen increased the static bending strength.

In Fig. 1 can be seen clearly that there was a tendency that changes in width, thickness (depth), and length will affect the MoE and MoR average values,. The increasing in width of the specimens will decrease the MoE and MoR as shown in treatment A (width 20mm), B (width 30mm) and D (width 40mm). Contrary to the width, increasing the thickness (depth) of specimens will increase the MoE and MoR values as shown in treatment A (depth 20mm), C (depth 30mm) and E (depth 40mm). As well as increasing the length of specimen along with the increasing the depth will increase the MoE and MoR as shown in treatment A (length 360mm), C (length 540mm) and E (length 720mm). The test shows that the specimens tested with flatwise orientation will have lower MoE and MoR values than edgewise orientation.

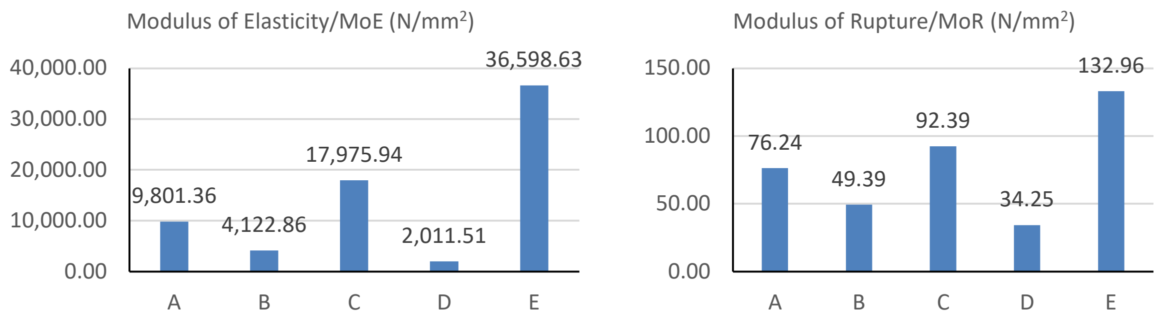

FIGURE 1. Modulus of Elasticity (MoE) and Modulus of Rupture (MoR) of Red Meranti based on difference in width, depth, and length

The same tendencies to the Fig. 1 was from Bohannan [2] which state that the possibility of a low-strength zone appearing increases as the width is increased. After a force is applied to a wood beam, failure often happens across the width, then creeps to the depth of the beam, and once failure begins across the width, it does not stop at the depth of the beam. When the width fails, the stress increases, resulting in wood beam failure and decreased MoE and MoR.

The same effect of length and depth was from [4] that examination of proper span length/depth ratio range in measuring the bending strength of wood based on the elementary bending theory shows that the MoE increase with the increasing ratio of length (L) to depth (h) of the specimens.

To find out whether the tendency that occurs has an effect on the treatments (difference in size), and to determine the significant difference between average value treatments of MoE and MoR, the statistical Analysis of Variance (ANOVA) continued with the Least Significant Difference (LSD) test was carried out and the result shown in Table 4 and Table 5.

TABLE 4. Analysis of variance for static bending strength of Red Meranti based on difference in width, depth, and length

Modulus of Elasticity (MoE)		Modulus of Rupture (MoR)	
F-calc	F table (0.05)	F-calc	F table (0.05)
623.95*	2.58	236.08*	2.58

* There was significant effect of treatments to the static bending strength value at confident level of 95%.

TABLE 5. Least Significant Difference (LSD) Test for Static Bending Strength of Red Meranti Based on Difference in Width, Depth, and Length

Treatments	Modulus of Elasticity (MoE)		Modulus of Rupture (MoR)	
	Average (N/mm^2)	LSD 0.05	Average (N/mm^2)	LSD 0.05
A	9,801.36a		76.24a	
B	4,122.86b		49.39b	
C	17,975.94c	1,597.82	92.39c	4.35
D	2,011.51d		34.25d	
E	36,598.63e		132.96e	

a, b, c, d, e = notification with different letter means there was significant difference between treatments, notification with same letter means no significant difference between treatments.

Analysis of Variance in Table 4 shows there was significant effect of treatments based on difference size in width, thickness (depth) and length specimens to the MoE and MoR of Red Meranti wood specimens. This means that changes in size (width, depth and length) of the specimens or the wood beam will affect to the MoE and MoR values.

The LSD test in TABLE 5 shows that there was a significant difference between all treatments on MoE and MoR test (by calculating the absolute subtraction between the average values of all treatments, and compared to the LSD value at the 95% confidence level). The results shows that there was significant difference between each treatment caused by the treatment of differences in specimen size. Statistically, the changes in the size of the wood material will cause the static bending strength value (MoE and MoR) to be significantly different.

The simple size effect theory that describing as the weakness link connection in chain, where increasing the dimensions (length, depth, and width) or more connections of a material the lower the strength, implies the absence of any characteristic of length i.e. microscopic structure or microstructure of material, and also if the material contains non homogenous like wood, also does not apply to all types of loading (mostly applicable to tensile test, but not always proper to another test like bending and shearing), the weakness link connection in chain probably more proper to tensile strength. Abu Bakar and Saleh [6] found that there is a cumulative probability with the Weibull's theory from brittle fracture in tensile strength in meranti timber, where Weibull's cumulative curve can be idealized as the cumulative probability curve for tensile strength of meranti timber, and further concluded that the decrease in tensile strength was caused by an increase in volume.

The simple link weakness theory cannot be used directly, because the bending strength test of Red Meranti specimens in this research do not met the requirements of this theory as weakness link connection in chain.

CONCLUSION

ANOVA shown there was significant effect of treatments to the MoE and MoR, the LSD test shown there was significant difference between treatments to the MoE and MoR test. Increasing in width of Red Meranti wood will cause a decrease in average Modulus of Elasticity (MoE) and Modulus of Rupture (MoR). Increase in depth and length will cause an increase in average Modulus of Elasticity (MoE) and Modulus of Rupture (MoR). Beams that are loaded with edgewise orientation have better Modulus of Elasticity (MoE) and Modulus of Rupture (MoR) than flatwise orientation. The simple link weakness theory cannot be used directly, because bending strength specimens do not meet the requirements of this theory, the weakness link connection in chain probably more proper to tensile strength.

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